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# THE UNIVERSITY OF KANSAS SPACE TECHNOLOGY LABORATORIES

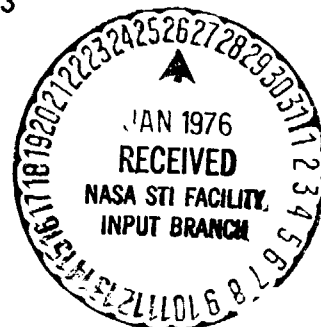2291 Irving Hill Dr.— Campus West    Lawrence, Kansas 66044

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## TOWARD PROOF OF SATELLITE ANEMOMETER CONCEPT

Final Report
Contract NAS 9-13356

December 1, 1972 – June 30, 1973

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Prepared by: _____
John Claassen

Approved by: _____
R. K. Moore

# TOWARD PROOF OF SATELLITE ANEMOMETER CONCEPT

## I. INTRODUCTION

In the early stages of planning satellite applications, it was proposed that ocean roughness could be measured from a spacecraft. From ocean roughness parameters it was theorized that both sea state and ocean winds could be inferred. It is known that sea state information is useful in cueing and routing ships over the seas so as to minimize transit time and hazards. On the other hand, wind information is important for forecasting weather. From knowledge of wind speed and direction the meteorologist is able to infer the surface pressure gradient. This parameter together with other remotely sensed data should make it possible to predict weather over the oceans and improve forecasts over land.

The usefulness of this information is already exhibited by the fact that in major shipping lanes, such as the one between North America and Europe, ships regularly transmit timely weather information to forecast centers. However, over most of the ocean, too few ships are present to permit adequate wave or weather forecasting.

Since this realization microwave radar and radiometer methods have been proposed and investigated for measuring wind speed and direction over the ocean. The wind response for each sensor has been independently demonstrated either from towers or aircrafts. Collecting data for a wide range of wind and sea conditions from either observational platform requires large amounts of effort and time. In contrast the speed and altitude of an orbiting spacecraft permits rapid and more complete coverage of these conditions. The S-193 oceanographic program jointly proposed by New York University, the University of Kansas and National Environment Satellite Service of NOAA is specifically designed to demonstrate the operational feasibility of measuring ocean surface winds on a global basis with a composite radar-radiometer sensor. Near-simultaneous radiometric/scatterometric measurements offer a better opportunity to make improved estimates of surface winds through a variety of atmospheric conditions.

The organization of the program appropriately reflects the user, scientist and engineer team essential to a successful execution of the program. The University of Kansas primarily fills the engineering role on this team. To this end studies of the

sensor-scene interaction, the sensor performance, and system design are conducted on a continuing basis. Under this contract the University of Kansas is contributing support in developing interpretational techniques for the joint measurements, designing experiments to verify the joint interpretation techniques, predicting the observations from theory, evaluating system effects on the measurements and developing system design criteria.

## II. WORK ACCOMPLISHED

During this first contract period theoretical efforts have shown how the sea spectrum, recently proposed by Pierson and Stacy [1] from various measurement sources, can be employed in scattering and emission theories. At this writing the spectral information has been incorporated in a composite surface scattering theory developed in previous efforts [2]. The original theory was derived for an anisotropic sea surface, however to simplify computations and to await better definition of the anisotropic character of the sea surface, backscatter was predicted for an isotropic sea surface. A "confused" sea is representative of an isotropic surface although full development is not anticipated under a "confused" condition. The predicted backscatter response at 8.91 GHz to a fully developed isotropic sea at various wind speeds is shown in Figures 1 and 2 for vertically and horizontally polarized observations, respectively. The family of graphs represents the wind response at the indicated incident angles. These results compare favorably with empirical observed wind responses derived from NRL backscatter data at the same frequency after a bias is removed from the data. Representative empirical wind responses with the bias disclosures included are shown in Figure 3 and 4. The theoretical wind responses exhibit stronger wind dependence than the empirical trends at large wind speeds. The difference may possibly be attributable to the fact that the theoretically derived responses are for fully developed seas and that the spectral representation by necessity does not account for non-linear effects such as wave breaking and foam that occur at large wind speeds. Typically stronger wind dependence is observed in the horizontal polarized observations, both theoretically and empirically. This feature is attributed to large structure reinforcement of the small structure return. Other theoretical
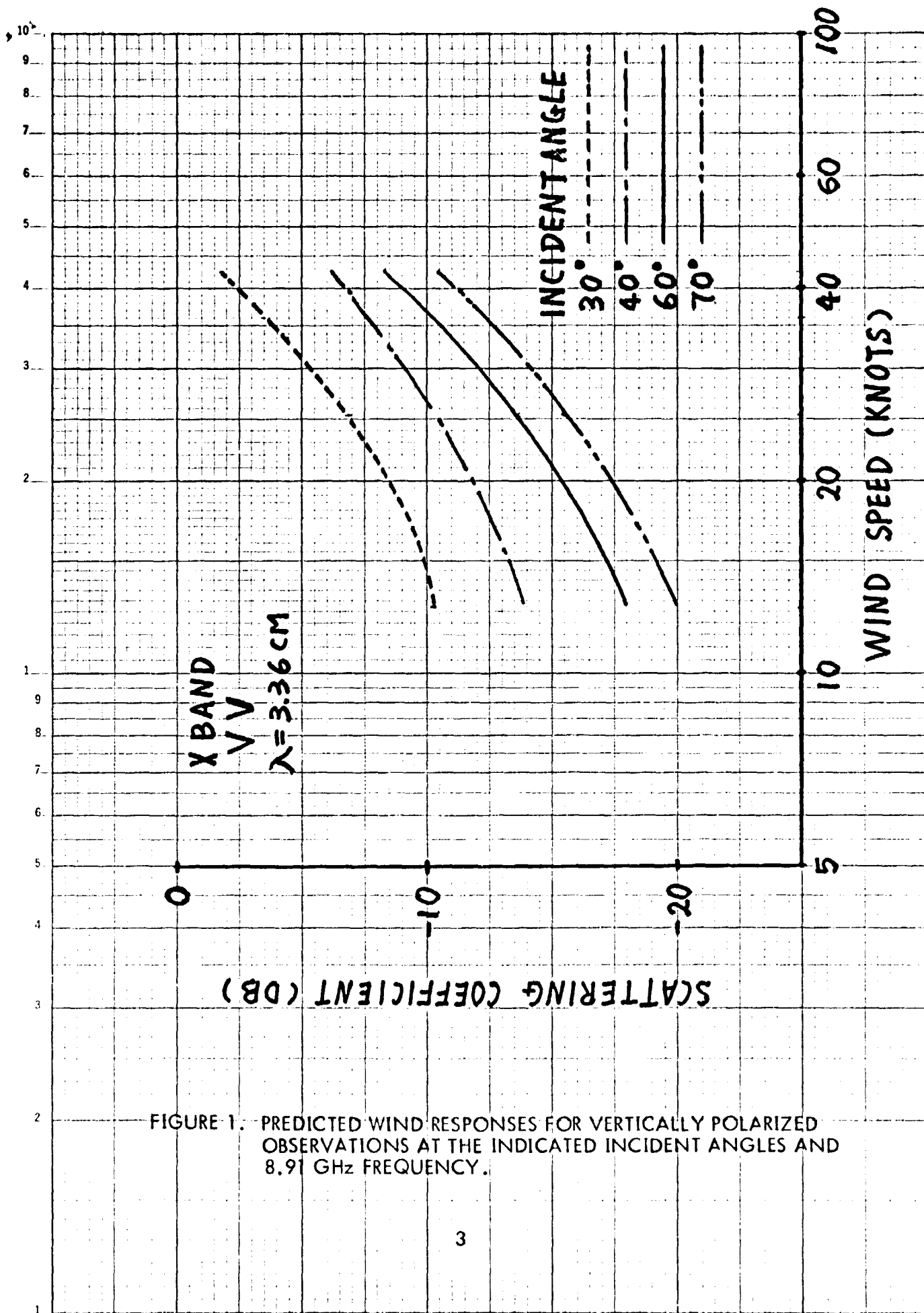
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FIGURE 1. PREDICTED WIND RESPONSES FOR VERTICALLY POLARIZED
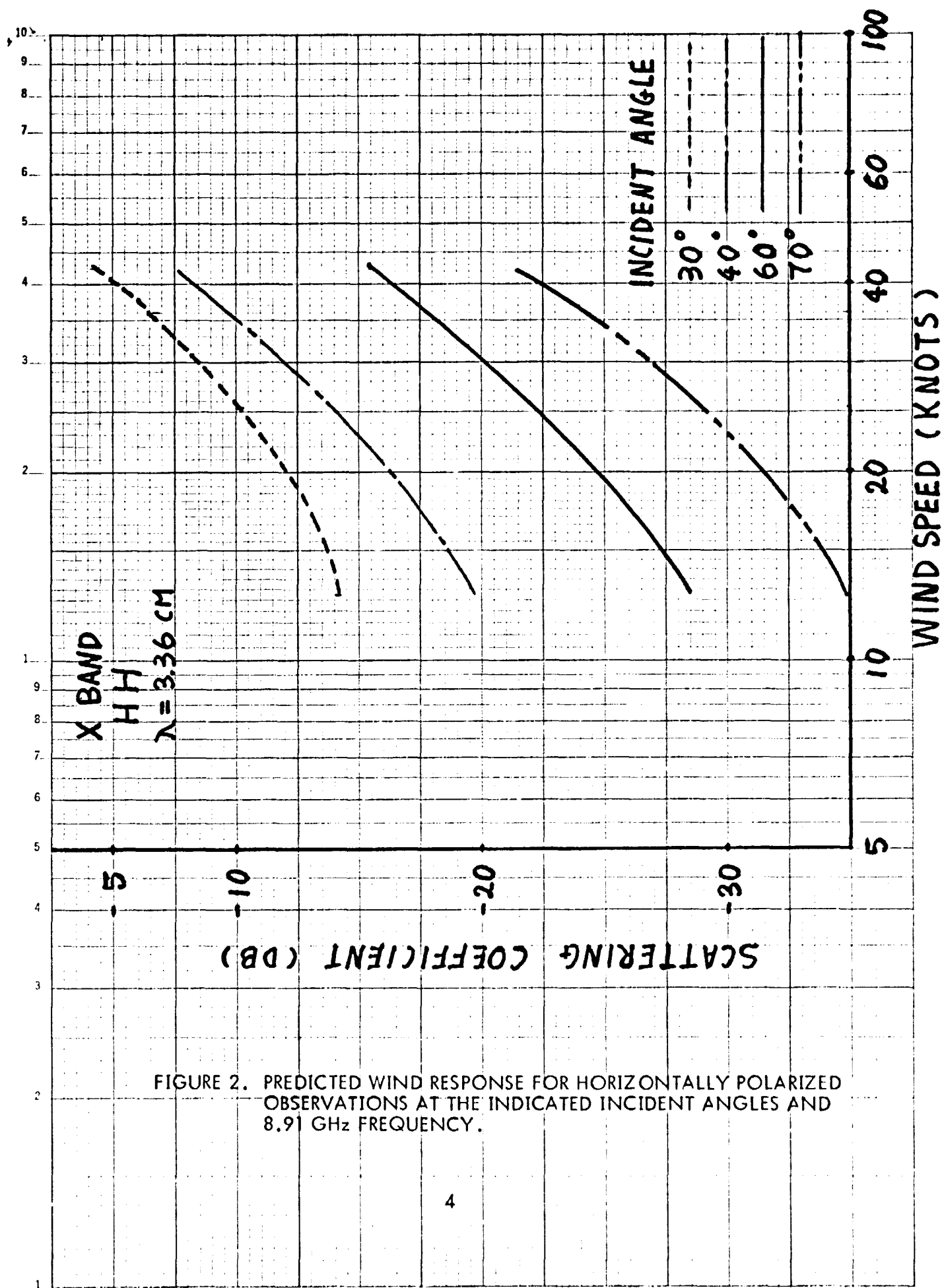OBSERVATIONS AT THE INDICATED INCIDENT ANGLES AND
8.91 GHz FREQUENCY.

3

FIGURE 2. PREDICTED WIND RESPONSE FOR HORIZONTALLY POLARIZED OBSERVATIONS AT THE INDICATED INCIDENT ANGLES AND 8.91 GHz FREQUENCY.
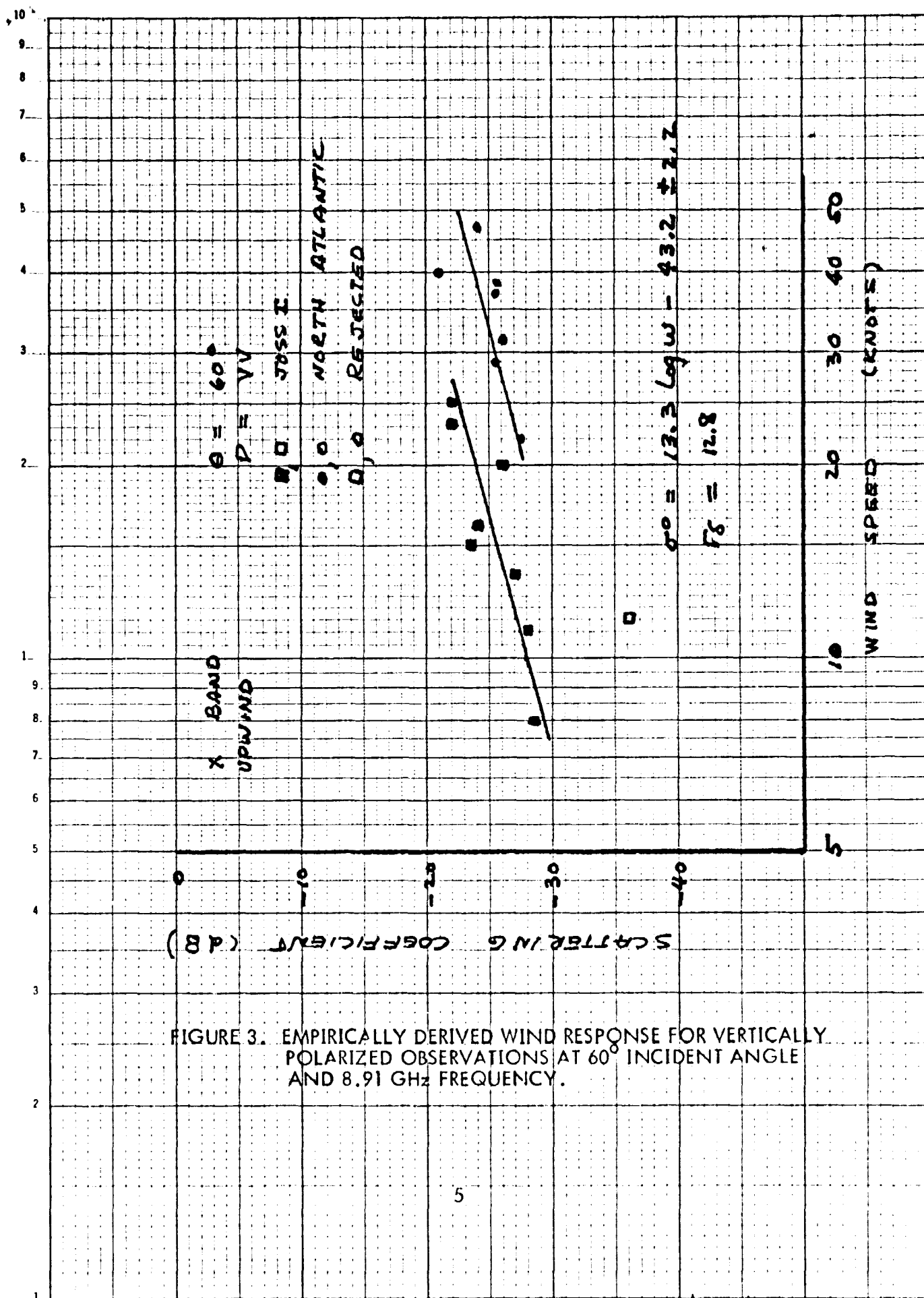
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FIGURE 3. EMPIRICALLY DERIVED WIND RESPONSE FOR VERTICALLY
POLARIZED OBSERVATIONS AT 60° INCIDENT ANGLE
AND 8.91 GHz FREQUENCY.

5

FIGURE 4. EMPIRICALLY DERIVED WIND RESPONSE FOR HORIZONTALLY POLARIZED OBSERVATIONS AT 60° INCIDENT ANGLE AND 8.91 GHz FREQUENCY.

6

aspects of this scattering problem and its extension to an anisotropic sea and to surface emission are presently under consideration.

In other efforts the influence of the atmosphere, clear or cloudy, on radar and radiometer observations are under investigation. The radar-radiometer (RADSCAT) concept [3] was developed to take advantage of the greater sensitivity of the radar to wind speed and of the radiometer to attenuation (emission) in the atmosphere, while allowing cross-checking of results at times of little or no attenuation. This is the joint interpretation aspect of the RADSCAT concept. It has been previously proposed that atmospheric attenuation may be removed when near-simultaneous observations by c composite radar-radiometer are made. Numerical studies have shown a relationship (Figure 5) between excess horizontally polarized emission induced by the atmosphere and atmospheric attenuation [4]. In conjunction with those studies it was also shown how the excess temperature (emission) could be estimated by comparing the scatterometer and radiometer observations and deriving atmospheric attenuation in an iterative algorithm. Efforts under this contract have shown that better potential to estimate atmospheric attenuation exists when observing the excess vertically polarized emissions at $55^{o}$. Hollinger's measurements [5] have shown that these emissions are wind insensitive, at least when whitecaps can be ignored. Predicted emissions based on Wu and Fung's theory [6] have theoretically verified this experimental observation (see Figure 6). The correlation between atmospheric attenuation and excess temperature for this polarization and the S-193 observation angle nearest $55^{o}$ is shown in Figure 7. Joint spacecraft and aircraft experiments to verify this joint interpretational tool have been designed and forwarded in earlier correspondence [7]. In view of the nearly full operational capability of SKYLAB after some initial problems, it is now important that aircraft support be planned and allocated for these experiments.

In related studies not yet completed the variability of clear sky conditions on radicmeter observations is under investigation. The variations induced by changes in temperature, pressure and water vapor profiles are treated numerically. The same computer routine will be employed to test the ability to translate sky temperature and attenuation from one frequency to another. This latter effort is important to the above described attenuation experiment.

New efforts are seeking appropriate statistical procedures to evaluate the sensitivities of the scattering and emission parameters to surface and atmospheric conditions. The sensor outputs and surface parameters are treated as members from
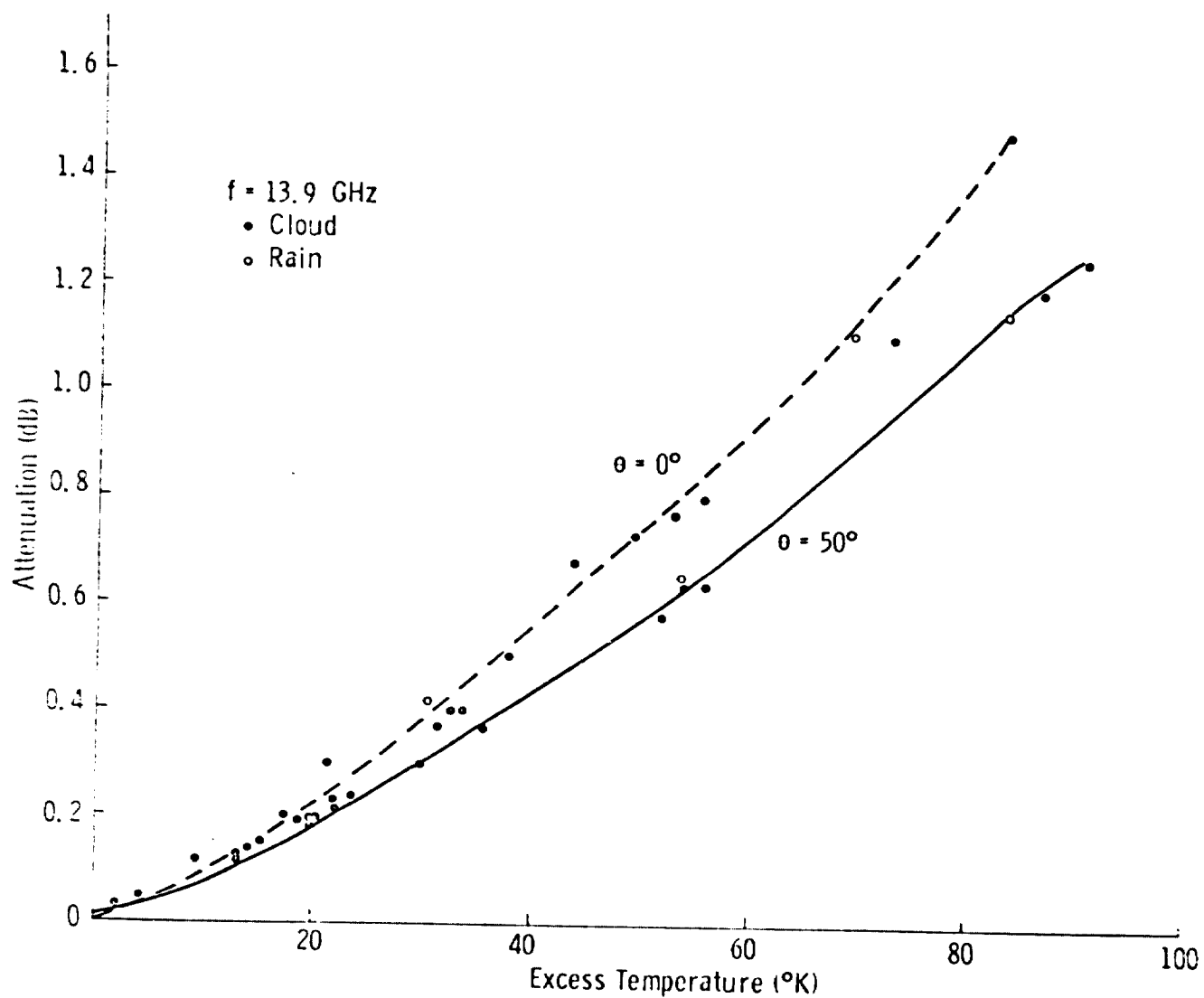
Figure 5. Calculated Relation Between Attenuation and Temperature Increase for a Radiometer Looking Down at a Flat Ocean Through Various Cloud and Rain Conditions.
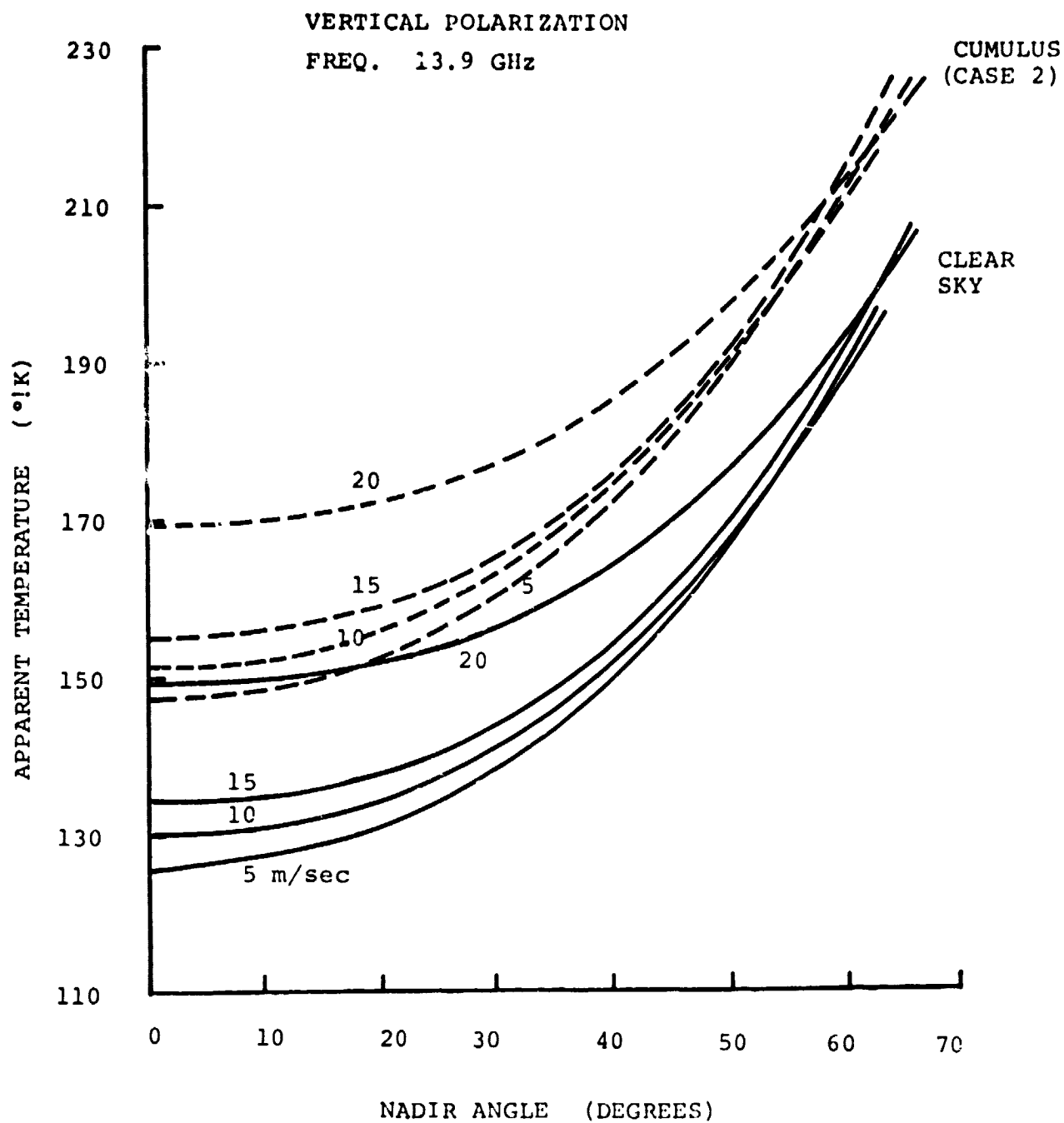
Figure 6. The Computed Apparent Temperature Characteristic for Vertical Polarization.
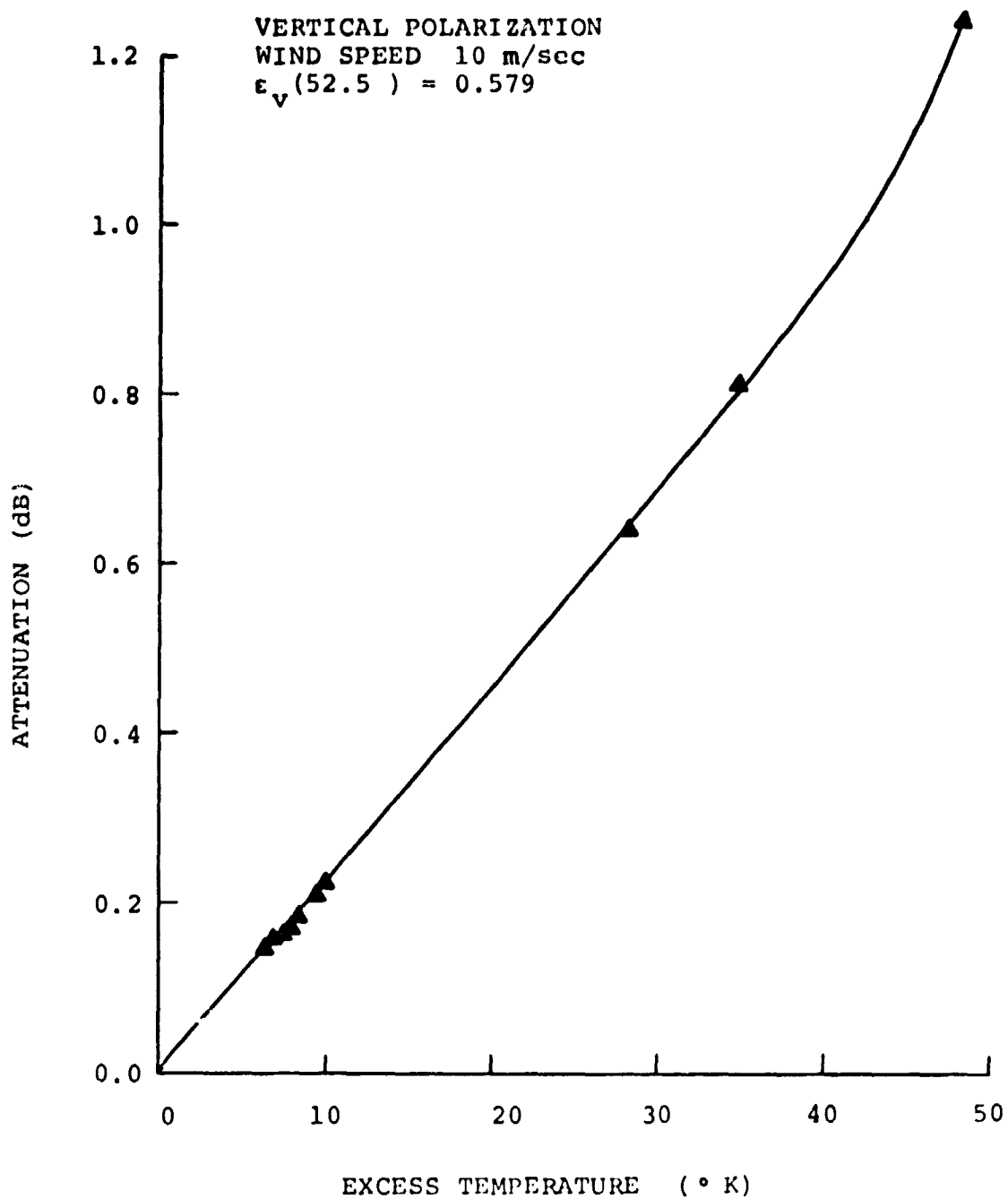
Figure 7. Relationship Between Attenuation and Excess Temperature
Observed at 52.5 Degrees.

a statistical population having a strong correlation between wind speed and backscatter or emission. Sensitivities of other known or suspected surface or atmospheric parameters on the wind measurement is the primary concern. At this writing analysis of covariance techniques and clustering techniques are potential approaches. Results of this effort when applied to S-193 data should be helpful in deriving interpretational algorithms and designing a satellite anemometer.

## III. CONCLUSIONS

In summary significant progresses have been made in the following areas that are essential to the analysis of the joint measurements over ocean by the radar-radiometer instrument.

1. A theory of radar sea return has been developed using Pierson and Stacy's sea model which compares favorably with experimental measurements especially in the wind speed region from 10-35 knots.

2. The influence of the atmosphere on the joint measurements by a radar-radiometer has been investigated. A relationship has been established between the excess emission and the attenuation by the atmosphere. It has also been shown that the excess emission could be estimated by comparing the radar and radiometer observations.

3. Joint spacecraft and aircraft experiments have been designed to verify the usefulness of the joint radar-radiometer measurements.

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[2] Fung, A. K. and H. L. Chan, "On Backscatter from Two-Scale Rough Surfaces," AGARD IXVII EPP Technical Meeting, June 21-25, 1971, Colorado Springs, Colorado.

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